

NanonisTM BP 4.5

SPM CONTROL SYSTEM BASE PACKAGE 4.5

KEY FEATURES

- Exceptional Signal Quality
- Expandable and Future Proof Hardware and Software
- Powerful, Flexible and Customizable User Interface
- Works with any SPM
- Most Advanced Measurement Techniques



SPACSTM



INNOVATION IN SURFACE SPECTROSCOPY AND
MICROSCOPY SYSTEMS

**SPECS leads the way in state-of-the-art
technology for electron spectroscopy and
scanning probe microscopy.**

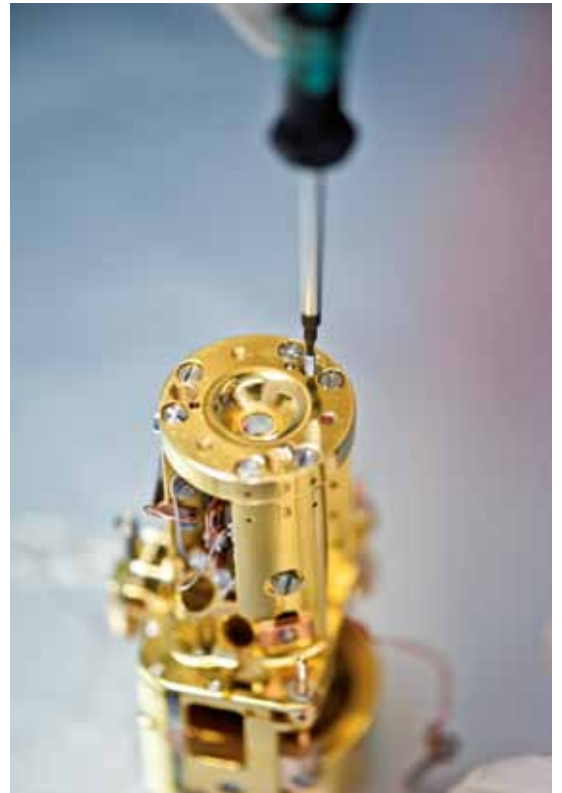


SPECS Surface Nano Analysis GmbH

SPECS headquarters, with more than 150 employees, is located in the center of Germany's capital Berlin, with subsidiaries in Switzerland (SPECS Zurich GmbH) and in the USA (SPECS Inc.). Furthermore, we have liaison offices and are represented all over the globe by our sales partners.

We are a team of scientists and engineers who have been dedicating their knowledge and experience to the development, design, and production of instruments for surface science, materials research, and nanotechnology since 1983.

Our key to success is know-how, experience, close contact to scientists from all over the world, customer orientation, reliable quality control, and dynamic research and development.



Nanonis BP 4.5

THE EXPANDABLE ENGINE FOR YOUR SPM PROJECT

The Base Package of the Nanonis Control System combines exceptional signal quality and a flexible, powerful, and user-friendly software interface making it the ideal choice for the most demanding SPM applications.

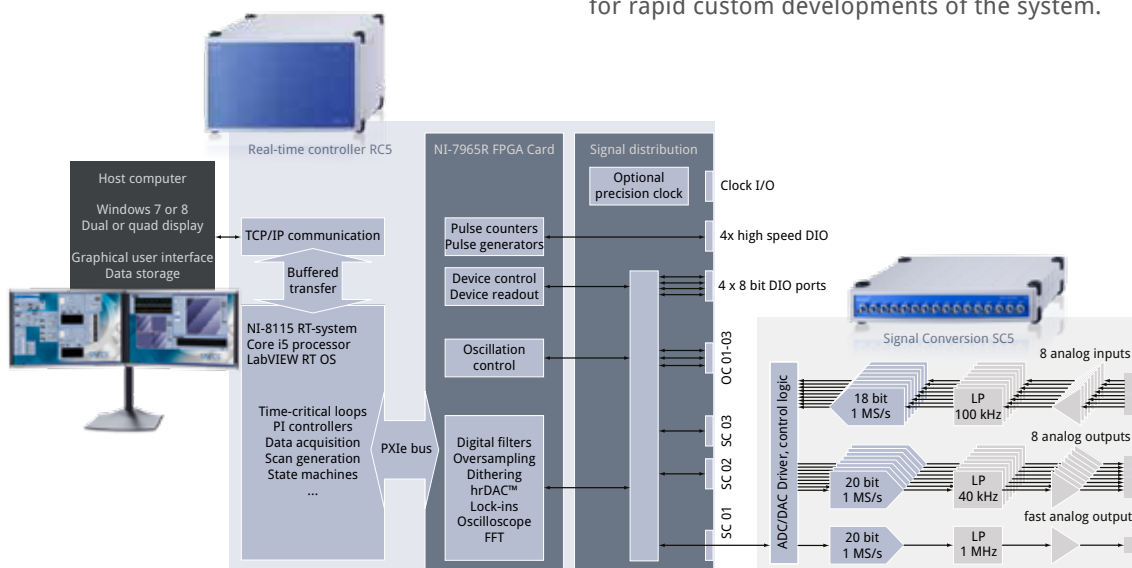
Nanonis SPM Control System

From signal conditioning and AD/DA conversion to fast signal processing via a comprehensive and clear graphical user interface, the Nanonis SPM Control System provides a powerful framework that can be further adapted and extended with a wide range of add-on modules. All basic processes such as Z-control, scan control, data acquisition, data monitoring, spectroscopy, atomic manipulation and lithography are included, allowing easy control of most STM and AFM operations.

Fully digital system

All analog signals are converted immediately into the digital domain, where all signal processing is performed, making them essentially immune to external noise and crosstalk and ensuring the best possible signal quality, which is crucial for SPM applications.

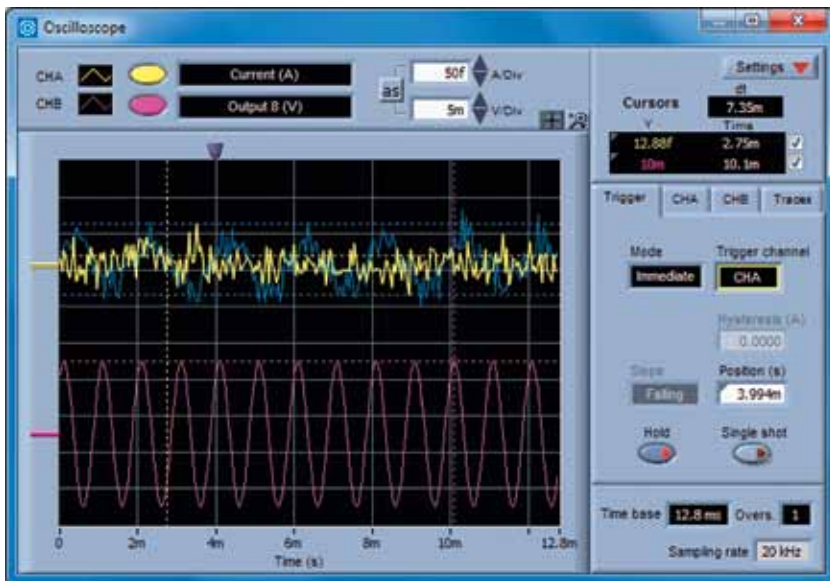
In combination with the powerful software package, signal routing can be adapted and optimized on the fly with the press of a button instead of adjusting external hardware cabling. A fully digital system is also flexible and scalable, since software adaptations are all that is needed for rapid custom developments of the system.



Simplified block diagram of the Nanonis Base Package 4.5

Plenty of channels

The generic analog interface provides 48 live signals: 8 inputs, 8 outputs and 32 internal signals, with up to 24 signals that can be acquired simultaneously. This allows the connection of signals including bias voltage, current, scan signals, lock-in signals, etc., and combination of different signals in the digital domain. The hardware is designed to support up to 24 inputs and 24 outputs, plus multiple PLLs for AFM operation, thus allowing operation of even the most complex measurement set-ups.



The dual-channel triggering oscilloscope makes monitoring, analyzing, and recording signals an easy task

This large number of live signals can not only be monitored, but also all signals are displayed as real world numbers in floating-point representation, with assigned SI units for immediate quantitative results, without the need of additional calibrations during data analysis.

Signal analysis and monitoring

All signals can be inspected with the FFT spectrum analyzer, dual-channel oscilloscope, signal charts, and history panels. Such fully digital and integrated software instruments are much more efficient in use, less invasive, better in performance, and lower in cost than their external counterparts.

The ability to digitally route live signals to software instruments during active measurements without any negative impact on signal quality is truly invaluable when optimizing the experimental set-up, eliminating disturbances and thus improving the quality of scientific results.

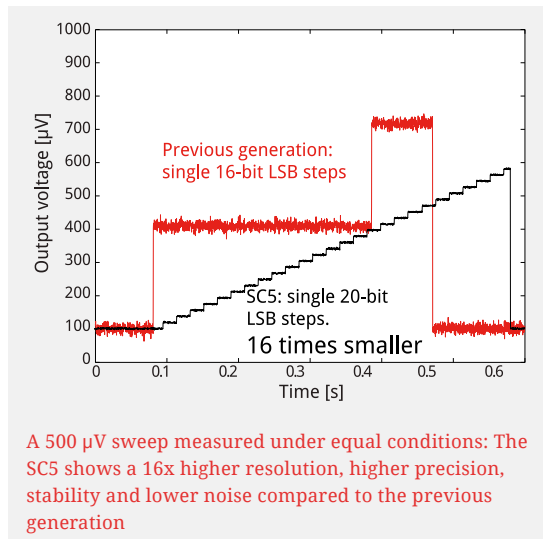
Highest signal performance

High resolution AD/DA conversion

“There is plenty of room at the bottom”, said Richard Feynman when he described his vision of the science that led to nanotechnology. Enormous resolution is required to reveal the smallest features, while maintaining a large dynamic range.

The signal frontend of the Base Package, the Nanonis SC5, uses the latest advances in AD/DA conversion technology, in combination with sophisticated digital filtering, oversampling, and dithering techniques, to provide the highest resolution.

22-bit resolution with patented hrDAC™ technology



All outputs of the SC5 use 20-bit resolution, 1-ppm precision DACs, the best available on the market. Just a few years ago, similar performance on multiple outputs would have been impossible to realize. The patented hrDAC™ technology turns these state-of-the-art converters into real 22-bit devices, which in a traditional approach would fill a rack with single-channel instruments and cost ten times as much. Measurements requiring smallest modulations with large offsets are thus possible without the need for drift- and error-inducing analog circuits or external mixers or attenuators. The impressive dynamic range also eliminates the need for switching gains, therefore coordinates are absolute over the full signal and scan range.

Adaptive oversampling high resolution data acquisition

A custom-designed input stage allows acquisition of the weakest analog signals, without compromises in dynamic range. The signals are digitized at an early stage with 18-bit AD converters running at 1 MS/s and then processed in the digital domain. Adaptive oversampling allows the ability to always obtain the best signal-to-noise performance for a given data acquisition rate. The user doesn't need to care about adjusting time constants, as the data acquisition automatically provides the best setting.

Lowest drift with temperature stabilization

Scanning probe microscopes require very stable signals over long measurement times. For this reason, the SC5 is equipped with a custom temperature-stabilized, high precision voltage reference. The reference has a very low inherent noise and drift. Temperature stabilization combined with thermal decoupling allows reduction of the temperature coefficient to below $3 \mu\text{V}/^\circ\text{C}$ and output drift to below $1.5 \mu\text{V}$ in 12 hours at 0 V.

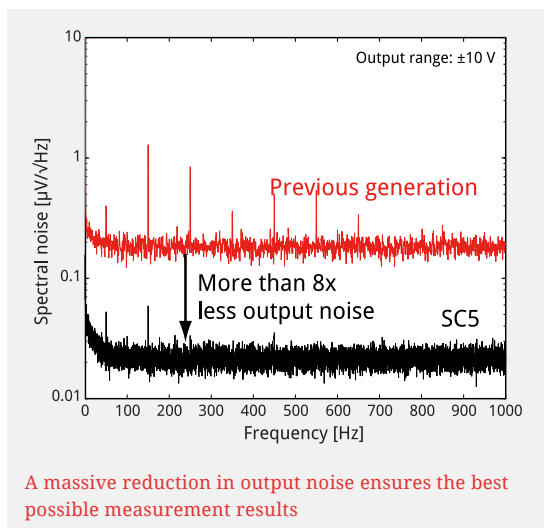
State of the art optional digital lock-in amplifier with 40 kHz bandwidth

DC signals are not the only strength of the SC5: Each output has a bandwidth of 40 kHz, and measurement schemes requiring a lock-in amplifier (e.g. dI/dV spectroscopy) can be realized very easily. With 1 MS/s sample rate, a THD+N larger than 93 dB ($18 \text{ V}_{\text{p-p}}$ at 1 kHz), linearity down to below -120 dB, up to 22-bit resolution, and multiple demodulators, the SC5 outputs offer a powerful measurement tool also for the most demanding AC experiments requiring low harmonic distortion and multiple harmonic demodulation.

Lowest noise

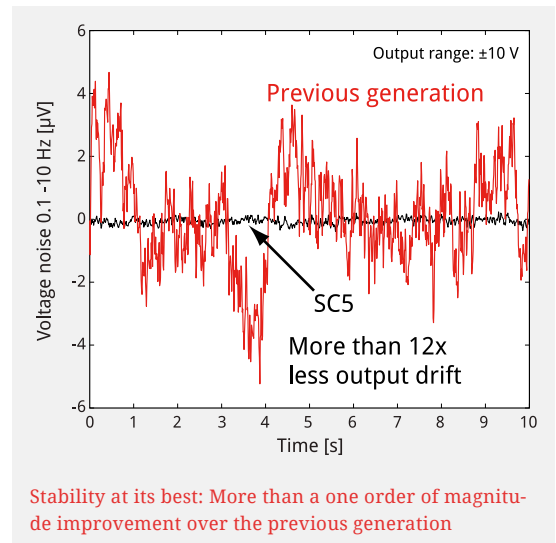
Lowest output noise floor

When experiments involve energies of a few μeV , high resolution alone is not the only prerequisite for a measurement interface: Low noise is of utmost importance, and the SC5 delivers impressive performance on both inputs and outputs. The noise floor of the SC5 lies below $25 \text{ nV}/\sqrt{\text{Hz}}$ with an output voltage range of $\pm 10 \text{ V}$. Despite its large bandwidth of 40 kHz , the output noise does not exceed $10 \mu\text{V}$ RMS at a measurement bandwidth of 300 kHz , meaning that the noise contribution of the SC5 is irrelevant in experimental situations.



Lowest 1/f noise outputs

In contrast to broadband noise, which can be easily filtered, $1/f$ noise cannot be eliminated and becomes an issue for experiments requiring signals to be very stable. The outputs of the SC5 have been designed keeping this in mind, leading to a noise level below 750 nV peak-peak ($0.1 - 10 \text{ Hz}$, $\pm 10 \text{ V}$ range), or about 2^{23} times smaller than the maximum output signal.



Additional analog and digital interfaces

High-speed analog output

Designed for providing sawtooth waveforms for coarse positioning applications, the 9th analog output of the SC 5 has a bandwidth of 500 kHz . With the flexible software function generator, the user can use this additional channel to output arbitrary periodic waveforms.

Digital inputs and output

32 bidirectional digital lines give sufficient flexibility for read-out and control of both Nanonis and external instruments. For high speed counting applications, four dedicated lines allow counting rates of up to 100 Mc/s .

User interface

Most advanced user interface for SPM

One of the key parameters determining the productivity of a measurement system is the user-machine interface, or, in avionic terms, the cockpit. The cockpit of the Nanonis SPM Control System, its user interface, is designed to be a pleasure to use, and to allow a safe, effective, and productive workflow, without limitations for the user. Let your SPM fly without crash landings.

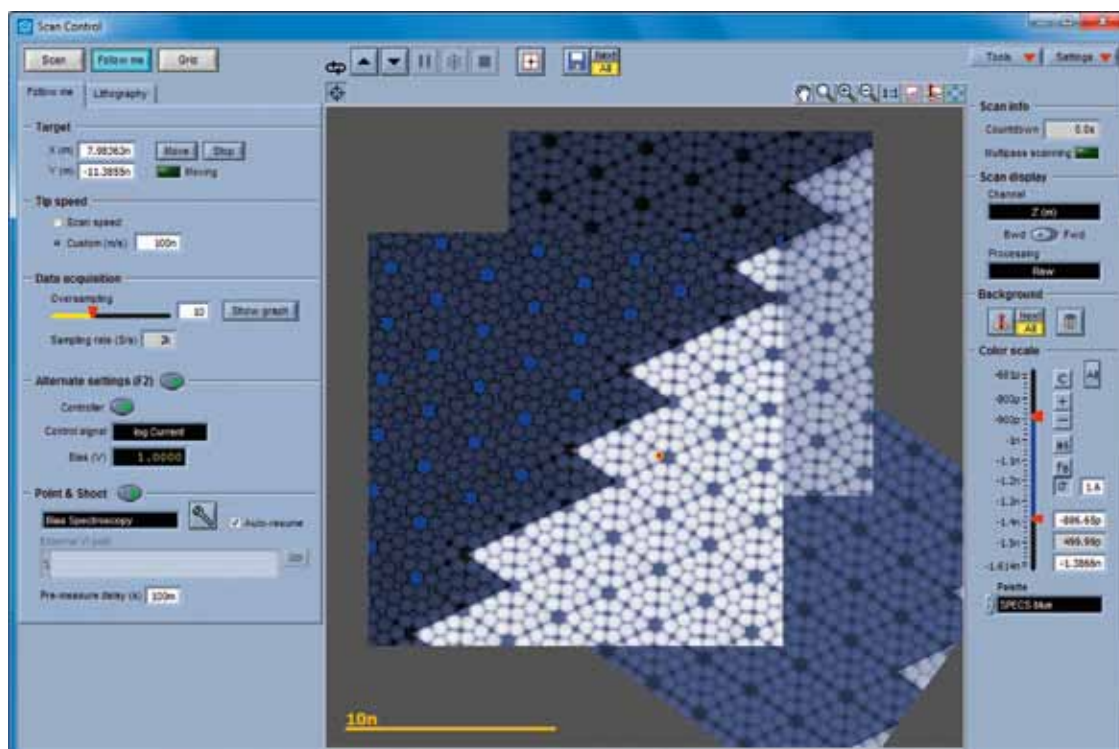
Interactive scan control

The scan control module is interactive and dynamic, allowing instantaneous control of the SPM tip in real-time and in any situation. Mouse button and scroll wheel control allows on the fly adjustments and data visualization optimization. By this, it is possible to zoom in, adapt scan frame parameters and paste multiple scanned images

to the background for reference. With up to seven scan windows it is easy to keep an overview over all acquired data. Arbitrary rotation of the scan plane on any of the X,Y and Z axis even allows to scan on the "walls" of high aspect-ratio samples.

Advanced multipass techniques with scripting functions

Many experimental techniques require the tip to be scanned multiple times on the same line while acquiring a scan image. The Nanonis multi-pass function allows multiple passes with different setpoints, speeds, bias voltages, at constant tip-to-sample distance, constant Z, or with any other parameter recorded during the previous pass.



The scan control module gives the user a complete overview of the sample and full control of the SPM tip at any time

Multiple passes can be time consuming when taking high resolution images, therefore optimizing the time for each scanned image can become crucial. The multipass function is therefore coupled with a scripting function, which makes it possible to run experiments like KPFM at real-time and deterministic speed just with a few script entries, and thus reduces time losses without the need for complex programming.

Advanced 2D and 3D spectroscopy

Advanced spectroscopy modules provide a set of flexible routines for experiments on a point, line, grid, or a cloud of points. Additionally, a “point and shoot” mode, where the user can interactively perform any experiment at a mouse click, and a fast spectroscopy mode allow precise and time-efficient spectroscopic measurements while scanning an image.

Spectroscopy modules are bias spectroscopy, Z-spectroscopy, and generic sweep where any output or parameter can be swept while any number of other selected channels can be recorded. Each module is designed to optimize precision and time requirements of the experiments. In the case of bias spectroscopy, a bias-dependent measurement resolution reduces the required measurement time per acquired spectroscopy curve, while disabling of the dI/dV AC modulation signal when in feedback improves reliability when determining the exact Z-position. In the same way, in the Z-spectroscopy module, a dedicated safety loop reduces the risk of tip crashes.

In addition to the already implemented modules, any user-defined experiment written in LabVIEW can be integrated into the spectroscopy functionality of the Nanonis SPM Control System, by using the Programming Interface.

Versatile Z-controller

The distance between tip and sample can be controlled by any signal or combination of signals. Quantitative parameters allow the application of control theory models and yield a further understanding of the tip-sample interaction. The user-configurable Z-controller allows on-the-fly switching between settings such as input signal and feedback parameters.

And when it takes days to get the first high quality image, a tip crash is the last thing a researcher wants to happen. The SafeTip™ function takes care of retracting the tip should a potentially harmful event be detected. Not only is this function very fast, and designed to reduce creep-induced drift, but it also gives the user a variety of choices what to do in such an event, ranging from engaging coarse motion to retract the tip further, to a scan resume function which limits data losses while scanning.

Easy expansion through add-on modules

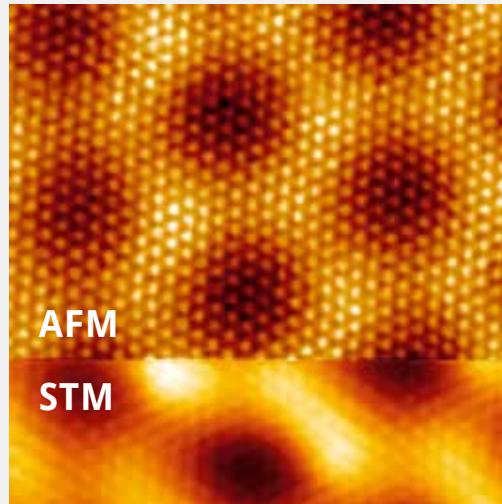
The modularity of the software is a key advantage in cost optimization: Additional software modules can be added when experimental needs require them. Even modules which are not available at the time of purchase of the Base Package, can be purchased at a later stage, making the instrument highly future-proof. The addition of new modules does not require any hardware or software installation, and can be performed in a very short time.

High resolution images measured with the Nanonis BP 4.5

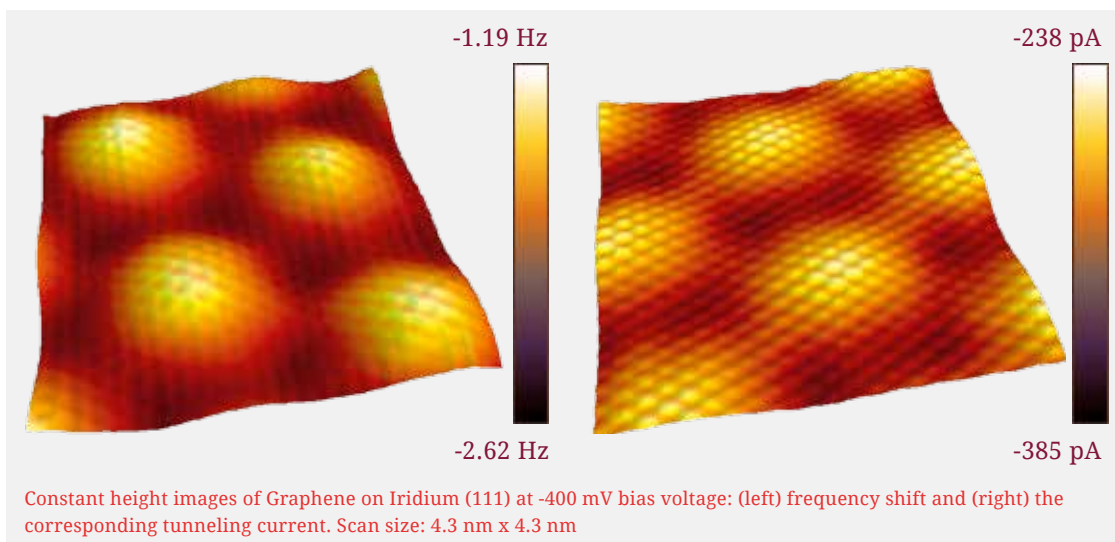
The modules include:

- Lock-in detector
- Programming interface
- Time-resolved measurement module with 1 MS/s oscilloscope/FFT
- Atom tracking
- Kelvin controller
- Interferometer controller

In addition to the modules listed above, pulse counters, a function generator for slip-stick piezo drive, a PI controller, and large number of coarse approach motor control modules for commercial and home-built microscopes are available on request.



Graphene on Iridium (111)
On the fly switch between NC-AFM (top) and STM (bottom) mode using a KolibriSensor.
Scan size: 6.7 nm x 6.7 nm
AFM: $\Delta f = 3.6$ Hz, STM: $U_T = +0.13$ V, $I_T = 1.8$ nA



Constant height images of Graphene on Iridium (111) at -400 mV bias voltage: (left) frequency shift and (right) the corresponding tunneling current. Scan size: 4.3 nm x 4.3 nm

LabVIEW Programming Interface for experiments

Flexibility for the user

Competitive advantage in research is often based on the modification of an instrument that allows the researcher to perform experiments in a way nobody else has done before. This is where the LabVIEW Programming Interface steps in: to give you the building blocks to design your own experiment.

The LabVIEW Programming Interface consists of libraries to access the controls and functions of the graphical user interface. It is used to automate experiments, sequences, calibration routines and experimental procedures. Polling of parameters and signals at high rates allows for supervision and alarm settings, and many other features.

Instead of using a simple scripting language, or a dedicated language, the Nanonis SPM Control System provides full access to all the features provided with LabVIEW: graphs, database access, convenient data handling, TCP/IP, GPIB, RS232, USB access to other instruments, signal analysis functions and much more.

Elaborated hardware design

Only best-in-class components

The electronic mainboard of the SC5 is a showcase for the best available active digital and analog electronic components on the market. Cheaper solutions leading to compromises have been discarded from the beginning, since only by meticulously choosing the best suitable components down to each single resistor, can the exceptional performance of the SC5 be achieved.





Future-proof and modular platform

Modular processing power

The “brain” of the Nanonis Base Package is the real-time controller RC5. By using the latest FPGA and CPU technology, the RC5 provides enough speed, connectivity and processing power for the most demanding tasks. Modularity doesn’t stop there either: Both FPGA and real-time modules are easily exchangeable, and can be updated should significantly faster modules be available in the future.

Linear power supply with automatic line voltage detection

The SC5 is powered by a linear power supply. Switching power supplies or DC/DC converters are not used anywhere in the instrument. Despite being equipped with a linear power supply, there is no need to manually adjust the line voltage to local circumstances: An intelligent circuit detects the line voltage and automatically configures the power transformer inputs.

Preamplifier power supply

An auxiliary power supply is available for powering external instruments like e.g. preamplifiers. With its low-noise, preregulated ± 15 V voltage with up to 300 mA current delivery capability, it makes external power supplies unnecessary.

Easy integration of additional experiments

When a new experiment is started, often not all requirements are already known in detail. This is no problem with the SC5 and its real-time controller RC5:

- The addition of one or more Nanonis Oscillation Controllers (OC4), which extends the frequency range to 5 MHz, is straightforward, should a larger signal bandwidth be required.
- Communication, triggering and control of additional external instruments is an easy task thanks to the various digital communication options of the RC5.

Hardware add-ons

Modular Control System

Modularity of the Nanonis SPM control system means that the hardware required for a given experimental situation can be tailored to the users' needs. This is the most flexible and at the same time cost-effective solution, and offers the best performance since each instrument is highly optimized. Hardware add-ons include the oscillation controller, high-voltage amplifiers, piezo drivers, and adaptation kits for commercial microscopes.

Oscillation Controller with PLL

Nanonis OC4 and OC4 Dual

The Oscillation Controller (OC4) with digitally integrated PLL adds dynamic AFM capabilities to the Nanonis Control System. The z-feedback can regulate on any signal coming from the mechanical resonator with any predefined SafeTip™ conditions. Imaging modes include among others: non-contact AFM, intermittent contact mode, phase imaging, dissipation. With an input bandwidth of 5 MHz, the OC4 can operate any type of cantilever, tuning fork, needle sensors, etc. and their harmonics. And, it can be used as a powerful digital lock-in amplifier.



High Voltage Amplifiers

Nanonis HVA4

The Nanonis HVA4 is a low noise, six-channel high-voltage amplifier specifically designed for nanopositioning applications using piezo elements. Three different models with maximum output voltages of ± 140 V, ± 220 V or ± 400 V let the user choose an optimal setup for his application.



With differential inputs and a noise spectrum density below $1 \mu\text{V}/\sqrt{\text{Hz}}$ at 300 Hz at gain 40 (input shorted), the HVA4 sets the standard for low-noise HV applications. The SNR of the HVA4 is so large that even with a $10 \mu\text{m}$ Z-range piezo tube, the noise level in Z corresponds to less than 2 pm (RMS), far below the corrugation of the sample.

Piezo Drivers

Nanonis PMD4



The Nanonis PMD4 is a high performance piezo motor driver, designed to drive piezo positioners with a very wide range of specifications. Owing to its patented output drive technology, the PMD4 is perfectly suited for driving piezo positioners in SPM applications, even under the most difficult conditions, e.g. at very low temperatures or with large capacitance piezo motors. The PMD4 is available with eight or sixteen output channels and a single waveform generator, or with eight output channels and two waveform generators. It can be remotely controlled in combination with a Nanonis SPM control system over its digital interface, or with the included handset. The amplitude of the output waveform can be varied continuously between 0 and ± 400 V, and its frequency continuously between 1 Hz and 20 kHz.

Nanonis PD5

The Nanonis PD5 combines the functionality of the HVA4 and of the PMD4 into a single enclosure. Five low-noise high voltage channels with the same specifications as the HVA4 are combined with eight outputs for driving low-capacitance piezo motors with software or handset control.



Adaptation kits

For use with commercial microscopes



Numerous adaptation kits are available to interface the Nanonis SPM Control System with most types of commercial microscopes including Omicron, Veeco (Bruker), JEOL, Createc, RHK and Unisoku. The original SPM cables connect directly to the pin-compatible interfaces, making a change of the control system extremely simple.

Specifications

Technical data

General	
Content of Delivery	Real-time controller RC5, Signal conversion SC5, software and license, unlimited updates and support for one year, host computer (Option)
Cases	Stackable benchtop cases, full metal enclosure
Operating Temperature	+5° C to +35° C
Compliance	CE
Warranty	One year parts and labor (EU: two years) on defects in material and workmanship
Documentation	User manual describing hardware and installation, online user manual for graphical user interface

RC5	
Dimensions	32.5 x 28 x 21 cm
Weight	7.8 kg
Power Supply	Built-in universal power supply, max. 200 W, 100 – 240 V, 50 - 60 Hz
Real-time System	NI PXIe-8115 real-time system with Intel Core i5 CPU 2.5 GHz, 2 GB RAM
Operating System	NI LabVIEW Real-Time OS
FPGA Card	NI PXIe-7965R
Connectivity	3 x SC5 max., 3 x OC4 max. Total of max. 4 frontends

SC5	
Dimensions	R 32.5 x 28 x 7 cm
Weight	4.2 kg
Power Supply	Built-in linearly regulated power supply, toroidal transformer, automatic line voltage detection. Max. 51 W, 100 – 240 V, 50 - 60 Hz
Electrical GND	10 kΩ AGND to chassis, decoupled from RC5

Analog Inputs (all specifications for ±10 V input range)	
Hardware Interface	8 x BNC connectors, differential
Differential Input Voltage Range	±10 V
Differential Input Impedance	2 MΩ
Analog Bandwidth	DC – 100 kHz (-3 dB), 5 th -order Butterworth low-pass filter
AD-converter	18-bit, no missing codes, 1 MS/s
Effective Resolution	20-bit @ 60 kS/s, 24-bit @ 240 S/s (oversampling)
INL	±2 LSB typical
DNL	±1 LSB typical
Input Noise Density	< 150 nV/√Hz @ 10 kHz, < 650 nV/√Hz @10 Hz
Measurement Noise	< 100 μVrms @ 1 MS/s, < 25 μVrms @ 60 kS/s, < 6.5 μVrms @ 240 S/s
12 h-Drift	< 80 μV (< 100 μV) @ 0 V (@ 9.9 V)
THD+N, 9 V Input Signal	> 120 dB @ 100 Hz, > 95 dB @ 1 kHz, > 70 dB @ 10 kHz

Analog Outputs (all specifications for ±10 V output range)	
Hardware Interface	8 x BNC connectors, referenced to AGND
Output Voltage Range	±10 V into 1 kΩ or larger (0 to +10 V with internal jumper per channel)
Output Impedance	<1 Ω, short circuit safe
Analog Bandwidth	DC – 40 kHz (-3 dB), 5 th – order Butterworth low-pass filter
DA Converter	20-bit, 1-ppm precision, 1 MS/s
Effective Resolution	22-bit, patented hrDAC™ technology with active glitch compensation

Analog Outputs (all specifications for ± 10 V output range)

INL	$< \pm 2$ LSB max. $< \pm 1$ LSB typical
DNL	$< \pm 1$ LSB max. < 0.5 LSB typical
Output Noise Density	< 25 nV/ $\sqrt{\text{Hz}}$ @ 100 Hz, < 75 nV/ $\sqrt{\text{Hz}}$ @ 1 Hz
Output Noise	< 200 nVrms (0.1 – 10 Hz), < 10 μ Vrms (10 Hz – 300 kHz)
12h-Drift	< 1.5 μ V (< 25 μ V) @ 0 V (@ 9.9 V)
THD+N, 9 V Output Signal	> 93 dB @ 100 Hz, > 93 dB @ 1 kHz, > 79 dB @ 10 kHz

Digital Lines

Ports	4 x 8 lines on four D-sub 9 female connectors
Direction	Input or output for each line
Signal	3.3 V TTL, max. 25 mA per line
Maximum Sampling Frequency	500 kHz

High Speed Digital Lines

Ports	4 x inputs and 4 x outputs on SMB male connectors
Signal	3.3 V TTL, max. 33 mA per line
Maximum Sampling Frequency	200 MHz

Clock

Ports	1 x input, 1 x output for active clock source
Frequency	10 MHz, square wave, 3.3 V
Accuracy	± 50 ppm (standard clock), ± 4 ppm (optional OCXO)

Graphical User Interface

Operating System	Windows XP/Vista/7/8 Windows 7 64-bit recommended
Min. Requirements	Intel Core Duo 1.5 GHz or equiv., 2 GB RAM, 100 GB HD, two 19" screens with at least 1280 x 1024 pixels
Recommended Configuration	Intel Core i5 2.5 GHz or equiv., 4 GB RAM, 1 TB HD, two 21" screens with 1600 x 1200 or 1920 x 1200 pixels
License	Unlimited in time, bound to RCS
Documentation	Online help, F1 for context sensitive help, tip strips for each control element, printed hardware user manuals with operation instructions for related software modules
Settings Configuration	For every session directory/ user, settings, parameters and screen layouts

Signals

Signals	48 signals (inputs, outputs and internal signals), up to 24 simultaneous signals for data display and acquisition
Data Transfer	Via TCP/IP, 2 kS/s default, up to 20 kS/s
Representation	32-bit floating point, real world physical units

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